National Institute of Standards & Technology

Certificate of Analysis

Standard Reference Material® 2003

First Surface Aluminum Mirror of Specular Reflectance

Series:

This Standard Reference Material (SRM) is intended for use in calibrating the radiometric scale of specular reflectometers at wavelengths from 250 nm to 2500 nm. SRM 2003 is a first surface aluminum mirror with a diameter of 5.1 cm and a thickness of 0.65 cm, and with a specular reflectance at a 6º angle of incidence of approximately 0.9. The serial number is located on the back of the mirror. The mirror is stored within an aluminum container fitted with Teflon® inserts so that nothing contacts the front surface of the mirror. Each mirror is individually certified.

Certified Values of Specular Reflectance: The specular reflectance was measured using the NIST High Accuracy Reference Reflectometer [1,2], which measures specular reflectance using an absolute technique. The certified specular reflectances are given in Table 1 at 30 wavelengths from 250 nm to 2500 nm. These reflectances are valid for unpolarized light incident at an angle of 6º from the normal of the front of the mirror, over the central 20 mm diameter of the mirror, and at an ambient temperature of 20 ºC ± 3 ºC and relative humidity of 40 % ± 10 %. The components of uncertainty for the certified specular reflectances are given in Table 2.

Expiration of Certification: The certification of this SRM is deemed to be valid, within the uncertainties specified, for a period of **two years** from the date of certification specified in Table 1, provided the mirror has been handled in accordance with the instructions given in this certificate. This SRM may be recertified if the mirror surface has not been altered, contaminated, or damaged; however, acceptance for recertification is contingent upon inspection by NIST. For acceptance inspection and recertification information, contact E.A. Early of the NIST Optical Technology Division by telephone (301) 975-2343, fax (301) 840-8551, or e-mail edward.early@nist.gov.

Maintenance of SRM Certification: NIST will monitor this SRM over the period of its certification. If substantive changes occur that affect the certification before the expiration of this certificate, NIST will notify the purchaser. Return of the attached registration card will facilitate notification.

Caution to User: This SRM is fragile and must be handled with extreme care so that nothing touches the exposed aluminum surface. The user should not attempt to clean the mirror as such action will adversely affect the aluminum surface.

The technical measurements leading to certification of this SRM were performed in the NIST Optical Technology Division by E.A. Early and M.E. Nadal. The overall direction and coordination leading to certification was provided by R.D. Saunders of the NIST Optical Technology Division.

The initial research and development of this SRM was conducted in the NIST Radiometric Physics Division (now the Optical Technology Division) by V.R. Weidner and J.J. Hsia.

The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the NIST Standard Reference Materials Program by J.W.L. Thomas.

Albert C. Parr, Chief
Optical Technology Division

Gaithersburg, MD 20899
Certificate Issue Date: 14 August 2000

Nancy M. Trahey, Chief
Standard Reference Materials Program

Handling Instructions: When not in use, the mirror should be properly stored in its original container. Airborne particulates, aromatics, and improper handling will adversely affect the condition of the aluminum surface. Under the best of handling conditions, the delicate aluminum surface may become contaminated and cannot be restored to its original specular reflectance by cleaning. Lint-free gloves (nylon or latex) should be used when handling the mirror to prevent fingerprints on the surface. Extreme care must be exercised when removing dust from the mirror. Gently use a very clean air bulb so that no damage is done to the aluminum surface. It is strongly recommended that a face mask be worn to prevent contaminating the mirror with vapors or particles from the mouth or nose.

Source and Preparation of Material: The mirrors were produced by the Muffoletto Optical Company Inc. of Baltimore, MD. Each mirror consists of a low thermal expansion glass substrate, Cervit C-101[1], polished flat to within 1/10 of a wavelength at 500 nm and smoothed to within 2.5 nm. The substrate was coated by evaporation of aluminum in three second at a rate of approximately 30 nm/s in a vacuum of 7×10^{-5} Pa. The mirrors were arranged in a hemispherical pattern above the evaporating element so that all mirrors were approximately the same distance from the element. No protective coating was applied to the surface.

Determination of Specular Reflectance: Newly manufactured mirrors were aged under normal laboratory conditions in glass containers for at least one year before being measured.

The specular reflectance measurements were made using the NIST High Accuracy Reference Reflectometer [1]. The mirror was placed in a mount on the sample goniometer so that the front surface of the mirror was on the axis of rotation. The collimated incident beam, with less than 1º divergence, a 10 nm spectral bandwidth and a diameter of 14 mm, was centered on the front of the mirror. The orientation of the mount was adjusted so that, at a goniometer angle of 0º, the incident beam was retroreflected. Radiant flux was collected and measured using a detection system mounted on an arm of the goniometer.

The specular reflectance was measured at 30 wavelengths from 250 nm to 2500 nm for the incident beam polarized both parallel and perpendicular to the plane of incidence. For each wavelength and polarization, the following measurement sequence was followed. With the mirror translated out of the incident beam, a signal proportional to the incident radiant flux was measured by the detection system, termed the incident signal. The reflected radiant flux was measured by centering the mirror in the incident beam and rotating it with the goniometer to obtain a 6º angle of incidence. The detection system was rotated so that the viewing angle was in the specular direction, and a signal proportional to the reflected radiant flux, termed the reflected signal, was measured. The sequence was completed by again measuring the incident signal. Also, after each signal reading, a shutter was closed on the monochromator and a dark signal was measured.

The sources of radiant flux into the monochromator were a xenon arc lamp for wavelengths less than 350 nm and a quartz-tungsten-halogen incandescent lamp for longer wavelengths. The optical detectors were a silicon photodiode for wavelengths less than 1100 nm and a cooled indium-gallium-arsenide photodiode for longer wavelengths. During the measurements, the ambient temperature was 20 ºC ± 3 ºC and the relative humidity was 40 % ± 10 %.

For each wavelength and polarization, the specular reflectance was calculated by subtracting the dark signals from the incident and reflected signals to yield net signals, then dividing the net reflected signal by the average of the net incident signals. The specular reflectance for unpolarized incident light was calculated by averaging the reflectances of both polarizations.

Discussion of Uncertainties: Uncertainties were calculated according to the procedures outlined in Reference [2]. Uncertainty components due to random effects are source stability and detector noise. The uncertainty contribution caused by these effects was evaluated from the standard deviation of repeat measurements of the specular reflectance of each mirror.

Uncertainty components due to systematic effects are the wavelength, incident and viewing angles, and sample uniformity. The standard uncertainties in the wavelength and angles were obtained from Reference [3]. The

[1]Certain commercial equipment, instruments, or materials are identified in this certificate in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

uncertainty caused by wavelength was evaluated from the derivative of the reflectance. The uncertainties caused by incident and viewing angles were evaluated from reflectances measured at angles differing from the nominal angles by 0.1º. The uncertainty caused by sample uniformity was evaluated from reflectances measured at 5 mm displacements, both horizontal and vertical, from the center of the mirror. All uncertainty components were assumed to have normal probability distributions.

The uncertainty components and contributions are given in Table 2 as a function of wavelength. The expanded uncertainty, $U = ku_c$, in specular reflectance is obtained from the root-sum-square of the uncertainty contributions multiplied by a coverage factor $k = 2$.

REFERENCES

[1] Proctor, J.E. and Barnes, P.Y., "NIST High Accuracy Reference Reflectometer-Spectrophotometer," J. Res. Natl. Inst. Stand. Technol. **101**, p. 619, (1996).
[2] Taylor, B.N. and Kuyatt, C.E., "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," NIST Technical Note 1297, U.S. Government Printing Office, Washington DC, (1994).
[3] Barnes, P.Y., Early, E.A., and Parr, A.C., "NIST Measurement Services: Spectral Reflectance," NIST Special Publication 250-48, U.S. Government Printing Office, Washington DC, (1998).

Users of this SRM should ensure that the certificate in their possession is current. This can be accomplished by contacting the SRM Program at: telephone (301) 975-6776; fax (301) 926-4751; e-mail srminfo@nist.gov; or via the Internet *http://www.nist.gov/srm.*

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Table 1. Specular Reflectance as a Function of Wavelength of SRM 2003

Serial No: 99G01 Calibration Date: 14 March 2000

Wavelength [nm]	Reflectance		Wavelength [nm]	Reflectance
250	0.9005		950	0.9186
300	0.9097		1000	0.9341
350	0.9127		1060	0.9453
400	0.9119		1100	0.9508
450	0.9128		1200	0.9585
500	0.9111		1300	0.9624
550	0.9084		1400	0.9650
600	0.9044		1500	0.9669
632.8	0.9008		1600	0.9678
650	0.8985		1700	0.9690
700	0.8897		1800	0.9699
750	0.8786		1900	0.9702
800	0.8643		2000	0.9708
850	0.8661		2400	0.9718
900	0.8933		2500	0.9721

Expanded uncertainties ($k = 2$) are given in Table 2.

Table 2. Uncertainty Contributions and Expanded Uncertainty (k = 2)
of the Specular Reflectance as a Function of Wavelength

Wavelength [nm]	Uncertainty Contribution					Expanded Uncertainty
	Repeatability	Wavelength	Incident Angle	Viewing Angle	Uniformity	
250	0.0005	0.0008	0.0000	0.0002	0.0003	0.0010
300	0.0005	0.0002	0.0000	0.0002	0.0003	0.0007
350	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
400	0.0001	0.0000	0.0000	0.0002	0.0003	0.0004
450	0.0001	0.0000	0.0000	0.0002	0.0003	0.0004
500	0.0001	0.0000	0.0000	0.0002	0.0003	0.0004
550	0.0001	0.0000	0.0000	0.0002	0.0003	0.0004
600	0.0001	0.0000	0.0000	0.0002	0.0003	0.0004
632.8	0.0001	0.0001	0.0000	0.0002	0.0003	0.0004
650	0.0001	0.0001	0.0000	0.0002	0.0003	0.0004
700	0.0001	0.0001	0.0000	0.0002	0.0003	0.0004
750	0.0001	0.0001	0.0000	0.0002	0.0003	0.0004
800	0.0001	0.0001	0.0000	0.0002	0.0003	0.0004
850	0.0001	0.0002	0.0000	0.0002	0.0003	0.0004
900	0.0001	0.0003	0.0000	0.0002	0.0003	0.0005
950	0.0001	0.0002	0.0000	0.0002	0.0003	0.0004
1000	0.0001	0.0001	0.0000	0.0002	0.0003	0.0004
1060	0.0005	0.0002	0.0000	0.0002	0.0003	0.0006
1100	0.0005	0.0001	0.0000	0.0002	0.0003	0.0006
1200	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
1300	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
1400	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
1500	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
1600	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
1700	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
1800	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
1900	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
2000	0.0005	0.0000	0.0000	0.0002	0.0003	0.0006
2400	0.0010	0.0000	0.0000	0.0002	0.0003	0.0011
2500	0.0010	0.0000	0.0000	0.0002	0.0003	0.0011